SOME TOPOGRAPHIC AND CLIMATIC CHARACTERS IN THE ANNUAL RINGS OF THE YELLOW PINES AND SEQUOIAS OF THE SOUTHWEST.

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The material here presented is part of a long-continued investigation of historical data contained in the annual rings of trees. Such data naturally are impressed by the environment, and the factor of the latter which interests us most is the climate. In this study as a whole, some 500 trees have been used, scattered in groups from California to Austria. About 110,000 rings have been dated and measured. The conclusion hitherto reached may be stated in a few sentences. First: the rings in the groups studied may be dated with practical certainty. This is not intended as a general statement for all trees in the world, because the identification of rings seems to increase in difficulty as the snowfall of winter decreases. Second: the yellow pines in the dry climate of northern Arizona give in their rings a rainfall record of considerable accuracy, namely, 70 per cent. in groups of trees near the rainfall record station. This is increased to an accuracy of some 85 per cent. by the application of a simple formula for conservation. Third: certain groups of wet-climate trees, especially about the Baltic Sea, give a very exact record of solar activity, as indicated by the relative sunspot numbers. Fourth: the rings in certain wooden beams used in prehistoric construction can be made to give us certain chronological facts. For example, it has been shown by this means that the old ruin of Pueblo Bonito in northwest New Mexico is forty to forty-five years older than that of Aztec, some fifty miles north of it. Fifth: three mechanical aids have been developed, a tubular borer for securing a core extending from the outside to the center of a beam or a tree, a recording microscope slide or micrometer for measuring ring widths, and a cycloscope for rapidly determining periodic effects in a plotted curve. By this last instrument as many as 34 curves of 500 points each have been tested in one day for all periods between 5 and 32 points; in this the curves were taken entire or in any number of parts.

At the present development of the investigation a review of the topographic effects observed in the trees seemed necessary. For such purpose a group of some 21 sequoias which had grown in Redwood Basin, 15 miles east of General Grant National Park, Fresno County, California, was used. It is understood that these trees had been cut down, and that radial pieces were cut from the stumps, shipped to the laboratory at Tucson, and there identified and measured. The trees were scattered for a mile along a valley whose steep slope was toward the north. The upper end is near the top of the mountain, but a spring supplies a small stream of water. The upper trees mostly had a very dry soil, while those below, some 600 or 700 feet in vertical measurement, had more level ground and greatly increased moisture. The average growth per century in the last 500 years was about 7.6 cm. The least was less than 4 cm. and the greatest was over 15 cm. The big-growing trees were mostly close to the water-course in the lower basin. The average growers were mostly around the edges of the basin, while the slow-growing trees were chiefly at the tops of the slopes. All this was as expected. Three larger growing trees close to the upper limit formed interesting exceptions. One was an infant sequoia, only 700 years old when cut, and therefore naturally a fast-growing tree. Another at the very highest point was about fifty yards above the spring and undoubtedly tapped an underground flow of water leading to it. Its type of rings was very similar to those in the basin. The third exception had very large rings, but they were full of sensitive variations like the slow-growing trees near by. That tree is probably over a pocket of water whose help increased its growth, but which failed in extremely dry conditions. It is evident, then, that with the sequoias moisture may control the growth up to a maximum fully four times as large as the minimum.

The type of ring and its adaptation to identification and study varies greatly with the moisture supply. The large rings of the quick-growing trees are either very complacent—that is, of the same size for many years in succession—or gross in character, which means extraordinarily large rings here and there and the whole grouping apparently subject to slow surges in size as one glances across the sequence from center to bark. Gross rings in one tree have about an equal chance of appearing or not appearing in any other tree near by. Since gross and complacent rings have little individuality, it is not always easy to identify their dates, especially if the outer layers of wood have been cut away as was usually done in felling the sequoias. On the other hand, the slow-growing, low-moisture trees are full of snappy irregularities which may be found in tree after tree, thus rendering accurate dating a remarkably easy process. It is also immediately evident that these latter sensitive trees give short-period variations far more accurately and effectively than the complacent trees.

A study of cycles of growth in the last five centuries of these twenty-one trees shows that often basin and upland trees vary together, and that in comparison with the others the well-watered trees show no lag of more than three years. Certainty in regard to no lag at all has not yet been reached.

Out of these latter tests has come the most interesting fact of all to students of cycles. The yellow pines of northern Arizona, much more sensitive than the upland sequoias, show the history of the eleven-year sunspot cycle in a prominent manner, even though other cycles are present. The fairly sensitive upland sequoias show the sunspot cycle, but other cycles are more prominent, and the eleven-year period has to be traced in multiples or harmonics to overcome the various interferences. But the complacent rapid-growing sequoias show the sunspot cycle only here and there, and so far no certain way has been found of using them in studying the history of that cycle.

This brings us to the consideration of the cycles in tree growth as climatic products. The ring itself is a result of the seasons. Variations in the rings in dry climates are found to match the rainfall. But the rings display marked cycles, and if these also can be interpreted as climatic, they are likely to prove of great assistance in studying climatic variations, because they stretch over great historic periods. The first line of evidence naturally is to compare the cycles in a tree sequence with cycles in rainfall records near by. This is done successfully with the Prescott trees, but the period over which such a comparison can be made is under half a century, and that is too short for satisfactory results. These trees show a 7.7-year cycle and the eleven-year sunspot cycle. The rainfall shows the sunspot cycle and a 7.7-year cycle, but the latter could be interpreted as anything between 5.5 and 8 years.

The next line of evidence depends upon the area over which cycles may be traced, for the common environment over a large area is climate. A test has been made between ten pines in southwestern Colorado, nine pines in northwestern New Mexico, fifty miles away, and nineteen pines at Flagstaff, Arizona, 200 miles southwest of the other groups. These three groups are largely identical in their cycles for the last two hundred years or more. This gives us much confidence that these cycles are real and are climatic in origin.

But still further evidence comes from a purely historical source and is of a kind full of interest on its own account. Professor E. W. Maunder, of England, in a recent letter, called attention to the prolonged dearth of sunspots between 1645 and 1715 and judged that if there were a connection between solar activity and the weather and tree growth, this extended minimum should show in weather conditions and in the trees. On receipt of the letter this period was immediately recognized as the interval in which the greatest difficulty had been found in tracing solar effects. In fact, in 1914, when the writer was trying to trace the history of the solar variations in the yellow pines, the difficulty between those dates almost led to the view that the trees were not giving this cycle. A present review of the eleven-year period in those trees confirms its well-marked existence from before 1400 to the middle of the seventeenth century. Soon after 1700 it reappears, but not in complete form until the latter part of that century.

The test was then carried to the sequoias and two difficulties were encountered. First, it was found that the slow-growing, sensitive upland trees were the ones which displayed the solar cycle, and, second, the interference by other cycles was such that the double period of about twenty-three years was a more satisfactory means of tracing the vicissitudes of the solar period. When these conditions were observed the same result was obtained as before from Arizona. The twenty-three-year period, in fact, begins to show change about 1635 instead of 1645 and continues on a ten-year cycle to the neighborhood of 1712, when the double sunspot period is resumed. Probably more and more evidence will be brought to bear on this point. Almost at the time of writing it is noticed that the Vermont hemlocks show a ten-year period from their beginning in 1654 to well on in the middle of the next century. The eleven-year period begins to show at about 1700 and becomes dominant in the latter part of that century. Modifications will doubtless be made in historical review of evidence in the trees of the prolonged dearth of solar influence at that time, but the evidence, so far as it goes, is wholly in favor of a pronounced effect in the growth of trees.

This correlation found in response to Professor Maunder's note therefore led to two results. First, it seemed to confirm strongly the idea that the cycles in the trees are not merely real, but they are related to weather elements and to cosmic causes; and, second, it gave added weight to the provisional history of solar variation derived from a study of the 3,200 years of sequoia growth. There has not been enough time yet to review that large mass of measures and derive a satisfactory history, but in conclusion a brief memorandum upon that point will be of interest. It is probable that from 1300 B.C. to well after 1000 B.C. the sunspot cycle was well developed; then it slowly decreased. From 300 B.C. on, it was increasing and was very conspicuous during the first two centuries of our era. Then it decreased and from 400 to 650 A.D. was only occasionally evident. From 650 to 850 or 900 it seems fairly continuous. Then it appears only occasionally until about 1250, when it again became fairly continuous with the changes in the seventeenth century above noted.

Thus there seem additional grounds for regarding the trees as supplying useful historic data and giving us long ranges of time over which to study the vagaries of our fickle climate.

In summarizing one notes a strong topographic effect in the trees of the Southwest, as expected; the maximum growth in well-watered ground is four times the minimum in dry ground and is accompanied by profound differences in type of ring; the eleven-year solar period (of the double-crested, dry-climate type) shows with rapidly increasing distinctness as one passes from the complacent, moist-ground trees of the basins to the very sensitive, dry-soil trees of the uplands and of Arizona. The climatic feature considered in this paper is the reality of certain possible climatic cycles found in the trees. That these cycles are real is attested by the extent both in time and space over which they are traced. This conclusion enables us to trace in the rings of the sequoia a provisional outline of solar variation for the last 3,000 years.

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